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September 2010

Working Paper 10-09

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September 9, 2010

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ABSTRACT

This study aims to achieve a two-fold research objective: first, to econometrically investigate hypothesized linkages between real estate and stock markets by fitting different classes of time-varying volatility model; second, to perform VaR-type stress testing by using the fitted asset price models. In so doing, we use data from Korea and U.S. so that asset price processes, in terms of mean, volatility, correlation, can be compared. In the econometric analyses, we estimate both a multivariate GARCH model that allows contemporaneous and time-varying shock correlations between real estate and stock markets and an univariate GARCH model that does not allow such correlation. Our results indicate that housing price volatilities in both countries are highly time-varying, with the Korean asset markets shown to be more volatile, and that non-consideration of asset market correlation under-predicts the risk embedded in real estate price dynamics. Policy implications of our findings in regard to stress testing and other issues are also discussed.

Key words: time-varying volatility, stress testing, and asset market correlation

JEL Codes: C22, E30, G11

I. Introduction

Real estate and stock represent two primary asset classes for investment in most countries. As a case in point, total value of residential real estate in Korea takes about 60% of household wealth; And that of corporate equities has another 25%. In comparison, the two asset classes amount to 32% (residential real estate) and 10% (stock market cap), respectively, in the U.S. In both countries, markets for these two assets are being integrated more and more in recent years, thanks mainly to expansion of real-estate backed indirect investment vehicles such as Real Estate Investment Trusts (REITs) and Real Estate Fund (REF).

In this paper, we have two-fold research objective: first, to econometrically investigate linkages between real estate and stock via VAR (Vector Autoregression) models with time-varying volatility; second, to apply the fitted asset price models to performing stress test in each market with consideration of asset correlation. In so doing, we use data from two countries – Korea and U.S. so that dynamic pattern of the linkages obtained from the model can be compared.

As to the linkages between two markets, we advance four alternative hypotheses in our empirical analyses: (1) *common factor hypothesis*, in that both sectors are influenced by common macroeconomic factors (e.g., GDP growth or unemployment rate) and, as such, are positively correlated in price dynamics (DiPasquale and Wheaton, 1995; Colwell, 2001; and others); (2) *investor sentiment hypothesis*, in that investor preference shifts from one market to the other depending on conditions of each market, making the two sectors as substitution to each other (Chan and Wang, 2002; Deng and Liu, 2009); (3) *market integration hypothesis*, in that the two sectors has been being integrated thanks to REITs and other real estate based indirect investment vehicles (Fisher, Ling and Narano, 2009; Ling and Narano, 1999); and, (4) *wealth effect hypothesis,* in that price boom-bust in one market can have indirect effect on the other through its impact on private consumption (Kim, 2009; Case, Quigley, Shiller, 2005; Belskey and Prakken, 2004; Iacoviello, 2004; Benjamin, Chinloy, and Jud, 2004). We survey main findings from literature regarding these linkages in the next section, and discuss our results in light of those findings.

We estimated actual linkages between residential real estate and listed corporate equity with two classes of GARCH (generalized autoregressive conditional heteroskedasticity) model – a multivariate GARCH model that allows contemporaneous and time-varying shock correlations across asset markets (the BEEK model, to be discussed later on), and an univariate GARCH model that does not allow shock correlation. Both models are well established in literature and are widely applied to various empirical studies. (Bollersleve et. al 1998; Ji et al. 2000; Park, 2000; Yoon et al. 2002; Nam et al. 2003; Fung and Yu, 2004; Baele, 2004). We use the fitted asset price models to perform VaR-type stress test and to discuss policy ramifications in terms of macro-prudence regulation and other issues.

Our results show that correlation between housing market and stock markets is not clearly shown in the mean equation in both countries. Nonetheless, the correlation between two the markets and volatility estimates for the housing markets are highly time-varying, with both short memory shock and long memory shock in the variance equations are statistically significant. Level of home price volatility in Korea is on average higher than that in the U.S. It is also shown that home price volatility tends to increase at times of turning point, implying heightened uncertainty in predicting price trends around then, and that the correlation between housing market and stock market increases sharply at the time of stress event, such as the Asian financial crisis. In terms of the stress testing, our results show that the univariate GARCH model under-predicts home price risk, implying that considering correlation between asset markets is important in such analyses.

The rest of the paper consists of the following five sections: a market comparison and literature survey (Section II), model specification (Section III); estimation results (Section IV); applying fitted models to stress testing (Section V); and, concluding remarks (Section VI).

II. **Sizing & Hypothesized Linkages**

Table 1 compares sizing of real estate and corporate equity sectors in Korea and U.S. In both countries, the total value of real estate, including both residential and commercial properties, amounts to several multiples of GDP, 3.2 times in Korea (as of EOY 2006) and 2.7 times in the U.S. (as of EOY 2005). It is also much larger than the size of exchange-traded corporate equities: that is, 4.1 times in Korea and 4.3 times in the U.S.

Table. 1

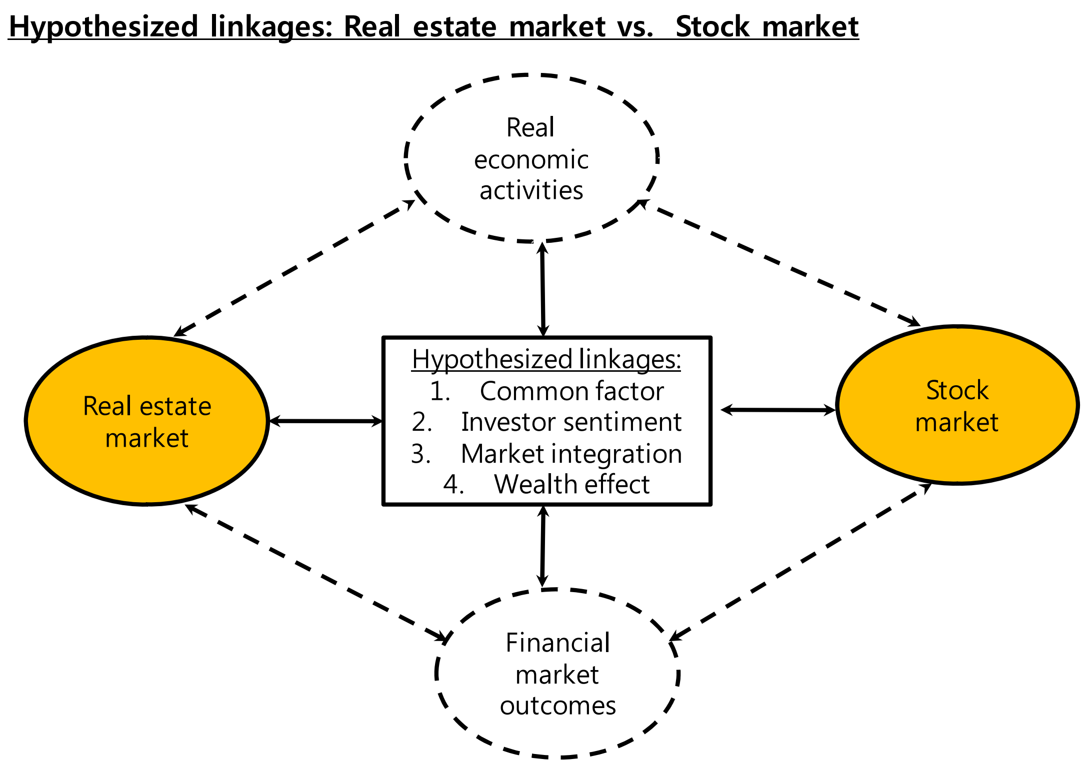
Real estate assets in Korea vs. U.S. (Preliminary)		
	Korea(a)	U.S.(b)
A. Real estate, total value	2,912.0	34.6
A.1 Real estate, residential	1,591.7	24.8
A.2 Real estate, commercial	1,320.3	9.8
A.3 REITs' total asset (c)	5.6	0.35
B. Houshold wealth	2,778.0	77.9
C. Stock market cap	704.5	8.1
D. GDP	908.7	12.6
A/B (%)	104.8%	44.4%
A.1/B (%)	57.3%	31.8%
A/C (%)	413.3%	427.2%
A.3/C (%)	0.8%	4.3%
A/D (%)	320.5%	274.6%

(a) Trillion Korean Won, end of 2006 value; 2007 National Wealth Survey & BOK
(b) Trillion US dollars, end of 2005 value; Re-quoted from Han and Cho (2008)
(c) 2.74 tr KRW REITs plus 2.86 KRW RE Funds, as of the end of 2009 (Kim, 2010)
(d) U.S. household wealth & stock market cap from Flow of Fund, EOY 2005;
($43.3 tr financial asset plus $34.6 tr total real estate asset)

Nonetheless, there are dissimilarities in two countries in terms of relative size of the two sectors. For example, in Korea, residential real estate takes a much bigger portion of household wealth than in the U.S., 57% vs. 32%. On the other hand, "the equitization" of real estate is much more advanced in the U.S. That is, after the rapid expansion in the 1990s and 2000s, the market for REITs in the U.S. amounts to $350 billion (as of 2005), about 4.3% of total stock capitalization. In comparison, the equitization is still in its infancy in Korea, with only 0.8% of total stock market cap as of today (in 2009).

As to linkages between two sectors, four hypotheses are advanced in the literature (as depicted in Figure 1). First, *common factor hypothesis* states that both real estate and stock are influenced by common macroeconomic factors, e.g., GDP growth, unemployment rate, inflation, and so on. In traditional real estate market models, these macro factors are treated as exogenous, that is, influencing, but not influenced by, real estate market outcomes. (DiPasquale and Wheaton, 1995; Colwell, 2001) However, as shown in the recent global financial crisis, boom-bust in real estate market can influence consumption and other elements of national account, i.e., the wealth effect, which will be further elaborated below.

Figure 1.



Second, *investor sentiment hypothesis* argues that the two markets are substitute to each other in that one market's upturn can lead to the other's downturn due to shift in investor's preference toward competing asset classes. For example, in the U.S., it is empirically shown that net asset values (NAV) of REITs tend to have a negative correlation with share values of other (conventional) corporate equities. (Chan and Wang (2002) and others) As a related micro evidence, Deng and Liu (2009) also report Chinese households' investment behavior toward real estate and equity assets, i.e., prepaying existing mortgage loans to put cashes-out home equity into the booming equity markets in China.

Third, *market integration hypothesis* argues that, thanks to REITs and other real estate based indirect investment vehicles, markets for two asset classes are being more integrated, leading to a positive correlation between the two. As an evidence, market betas of listed REITs in the U.S. are reported to be rising throughout the 1990s and converging to unity. (Fisher, Ling and Narano (2009), Ling and Narano (1999) and others) This effect is expected to be stronger in the U.S. than in Korea. However, there can be another channel of linkage in that some of key players, such as listed construction companies, play in both markets. In fact, it is shown that construction cycle tends to be the most pronounced leading indicator of real business cycle in the U.S. (Leamer, 2007), whose performance will influence both stock and real estate markets.

Finally, *wealth effect hypothesis* states that price boom-bust in one market can have indirect effect on the other through its impact on macroeconomy. In particular, various recent studies demonstrate that asset price changes tend to have impact on household consumption, about 2-8% change in the latter in response to one unit change in asset price. (Kim, 2009; Case, Quigley, Shiller, 2005; Belskey and Prakken, 2004; Iacoviello, 2004; Benjamin, Chinloy, and Jud, 2004) Existence of this wealth effect will increase correlation between the two markets, in a positive direction, as boom-bust in one market will be conveyed to the same in the other.[1]

[1] In addition, asset price bubble can play a role in linking the two markets. That is, optimal asset price at a particular point in time can be expressed as a sum of two components: the market fundamental value, or the discounted present value of forward-looking cash flows generated from the asset (e.g., rent per period in the case of housing); and, a deviation from the fundamental value, often termed as a bubble representing economic agent's expectation that she will sell the asset with capital gain in a future time period (i.e., the component in home price reflecting a pure demand for future capital gain): $P_t = \sum_{J=1}^{\infty}\left(\prod_{j=1}^{J}\frac{E_t[R_{t+j}]}{(1+E_t[r_{t+j}])}\right) + B_t = P_t^* + B_t$

Assuming a time-varying risk-free short rate, r_t, and permanent holding, the optimal value of residential property, P_t, under this definition is specified as a discounted present value of forward-looking rents, R_{t+j}, and the bubble, B_t.

Table below summarizes four hypotheses advanced, in terms of variables used in our econometric model and expected sign of endogenous variables (i.e., lagged home price change in stock price equation, and vice versa).

Table 2.

Common factor hypothesis	Exogenous variables (GDP, IR)	Positive
Investor sentiment hypothesis	Lagged endogenous variables	Negative
Market integration hypothesis	Lagged endogenous variables	Positive
Wealth effect hypothesis	Exogenous variables (GDP, IR)	Positive

In empirically fitting the price dynamics, various model frameworks are employed. As a reasonable and conceptually sound approach, a serially-correlated housing price model can be used. There are wide array of models to choose from under this approach, e.g., a vector-autoregressive (VAR) model (e.g., Sutton (2002)), and error-correction models (ECM) (e.g., Meen and Andrew (1998), and Capozza- Hendershott- Mack (2004)). In the U.S. and other countries, ECM is emerging as typical model framework in analyzing home price dynamics. For example, Glindro et al (2009) estimated a similar ECM model using a 1993-2006 panel dataset on nine Asia-Pacific countries. They estimated the fundamental housing value as a function of demand-side variables (real GDP, population, real mortgage rate, and the mortgage credit to GDP ratio), supply-side variables (building permits and real construction costs), prices of other assets (equity prices and exchange rate), and a composite index of institutional factors.

Nonetheless, GARCH-type time-varying volatility models are used in dynamic home price process (Chinloy, Cho, and Megbolugbe (1997), and Crawford and Fratatoni (2003)). For example, Crawford and Fratatoni compare three types of univariate home price models – ARIMA, GARCH, and Regime-Switching – and report that, while regime-switching model can perform better in sample, ARIMA models generally perform better in out-of-sample forecasting.

III. **Econometrics model**

In analyzing multivariate time-series data, the variance-covariance matrix should be in general satisfy two conditions: first, the volatility of returns is time-varying; second, correlations with other variables are shown not only with returns but also with volatility of returns.

1) AR(1) – GARCH(1,1) model : Bivariate GARCH Model

Conditional mean equation: AR(1) model

$$r_t^S = \beta_0^S + \beta_1^S r_{t-1}^S + \beta_2^S r_{t-1}^R + \varepsilon_t^S$$

$$r_t^R = \beta_0^R + \beta_1^R r_{t-1}^S + \beta_2^R r_{t-1}^R + \varepsilon_t^R$$

where r_t^S : returns to holding equity, r_t^R : returns to holding real estate asset

Conditional variance equation: GARCH(1,1)

$$h_t^S = \alpha_0^S + \alpha_1^S (\varepsilon_{t-1}^S)^2 + \alpha_3^S h_{t-1}^S$$

$$h_t^R = \alpha_0^R + \alpha_2^R (\varepsilon_{t-1}^R)^2 + \alpha_4^R h_{t-1}^R$$

where h_t^S : volatility of stock returns, h_t^R : volatility of real estate returns,

$$\varepsilon_t \mid I_{t-1} \equiv \begin{bmatrix} \varepsilon_t^S \\ \varepsilon_t^R \end{bmatrix} \mid I_{t-1} \sim MN(0, H_t) \text{ where } H_t = \begin{bmatrix} h_t^S & h_t^{SR} \\ h_t^{RS} & h_t^R \end{bmatrix}$$

In the above specification, β_2^S measures the return spillover effect of real estate market to stock market, while β_1^R shows the return spillover effect of stock market to real estate market. In a multivariate GARCH setting, h_t^{SR} indicates the covariance of returns between two asset markets but this market linkage is ignored in a univariate GARCH model. Assuming multivariate normality, GARCH estimation uses maximum likelihood to jointly estimate the parameters of the mean and the variance equations. The log likelihood contribution of each t observation is given by

$$l_t = -\frac{1}{2}\text{mlog}(2\pi) - \frac{1}{2}\log(|H_t|) - \frac{1}{2}\varepsilon_t' H_t^{-1}\varepsilon_t$$

where m is the number of mean equations.

We will specify the above model with three sectors including the bond market. We compile data for Korea and US, and will compare the results.

2) Conditional Dispersion Matrix

We assume that: CCC (Constant Conditional Correlation) is non time-varying; Diagonal VECH is assumed to be time-varying conditional correlation, as suggested by Bllerslev et. al (1988); Diagonal BEEK (Diagonal VECH) is a condition to relax parameter restrictions as suggested by Engle and Kroner(1995). And DCC (Dynamic Conditional Correlation) will be estimated with the time-varying conditional correlation as suggested by Engle (2001), Engle and Sheppard (2002).

Through the conditional dispersion matrix, we can estimate the time-varying shock correlations between the markets examined. Furthermore, we can estimate a trivariate GARCH model to examine shock correlations of three market return time series, and can assess how they change before and after key economic events. We also fitted city-level GARCH models for comparison, by using data from three localities in Korea (Gangnam, Gangbuk, and Busan).

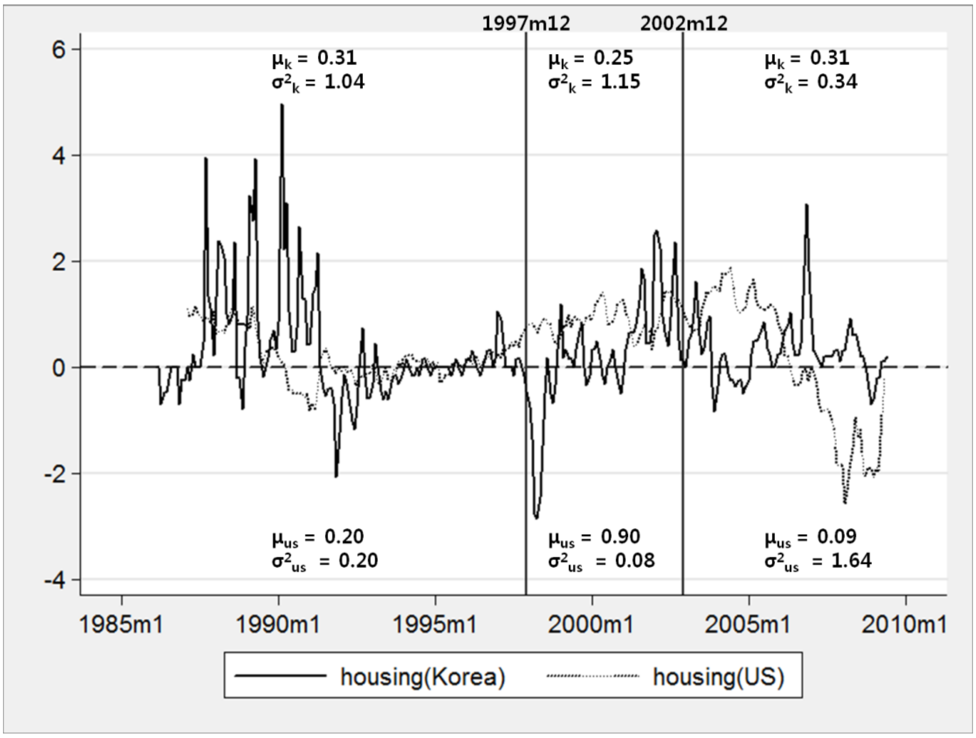
Data Description

We use publicly available home price and stock price indices from Korea and the U.S.: the Kookmin Bank's national level purchase home price indices for Korea, and the 20-city composite repeat sales index published by Fiserv (known as the Case-Shiller home price indices); the KOSPI index, the primary stock market index in Korean, and the S&P 500 index from the U.S. We also compiled the real GDP growth rates and long-term lending rates (to be elaborated) from public sources as well.

Housing returns in Korea appear to be more volatile than in the U.S., and are also time-varying with distinct mean and volatility figures in different time segments.

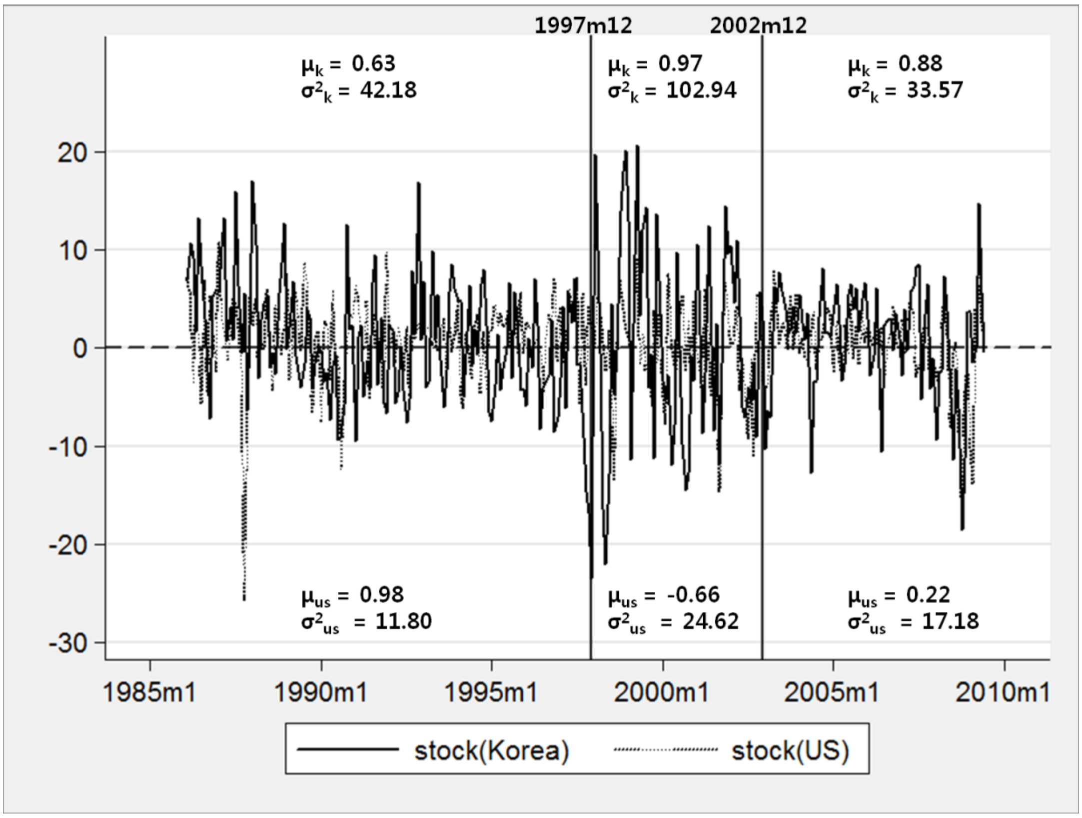
A significant volatility reduction is observed for the Korean housing return series in recent years, with sigma being 0.34 after 2002 compared to 1.04 in 1987-1997 and 1.15 in 1998-2002. Except the most recent time period (2002-2010), the volatility of Korean housing returns is higher than that in the U.S.

Figure 2. Housing Returns over Time (Korea & USA)



In both countries, stock returns appear to be less serially-correlated, but much more volatile, than housing returns. Between the two countries, the Korean stock price returns exhibit much higher volatility, in fact, several times higher than that in the U.S.

Figure 3. Stock Returns over Time (Korea & USA)



IV. **Estimation Results**

Multivariate GARCH model: AR (1)-GARCH(1,1) Model Estimation

Consider the market linkage between housing index and two financial markets (stock and interest rate)

Mean equation: AR(1)

$$\text{stock}_t = \beta_{01} + \beta_{11}\text{stock}_{t-1} + \beta_{21}\text{housing}_{t-1} + \beta_{31}\text{interest}_{t-1} + \beta_{41}\text{GDP}_{t-1} + e_{1t}$$

$$\text{housing}_t = \beta_{02} + \beta_{12}\text{stock}_{t-1} + \beta_{22}\text{housing}_{t-1} + \beta_{32}\text{interest}_{t-1} + \beta_{42}\text{GDP}_{t-1} + e_{2t}$$

where interest rate and GDP variables are assumed to be exogenous.

stock_t : KOSPI growth rate (in % return)

housing_t : housing price index growth rate (in % return)

interest_t: interest rate (in % change)

GDP_{t-1} : GDP growth rate

Define e_t=$[e_{1t}, e_{2t}]'$ and it is assumed to distributed normally with mean zero and covariance H_t.

A diagonal VECH model is employed as an ARCH model specification, under the assumption of time-varying variance and time-varying covariance[2]:

$$H_t = \Omega + A \otimes e_{t-1} e_{t-1}' + B \otimes H_{t-1}$$

variance equation

$\sigma^2_{t,\ j} = \gamma_{0,\ j} + \gamma_{1,j} e^2_{t-1,\ j} + \gamma_{2,\ j} \sigma^2_{t-1,j}$ where j=stock, housing

covariance equation

$\text{cov}_t^{i\,j} = \delta_1^{i\,j} e^i_{t-1} e^j_{t-1} + \delta_2^{i\,j} \text{cov}^{i\,j}_{t-1}$ where i, j=stock, housing

Multivariate GARCH model: AR (1)-GARCH(1,1) Model Estimation

Table 3. Time-varying correlation model : KOREA & USA

Diagonal VECH		Korea		USA	
		Stock	housing	stock	housing
Mean equation	β_{11}	0.320***		0.080	
	β_{21}	-0.035		0.279	
	β_{31}	0.010		-2.077*	
	β_{41}	-0.437		2.306*	
	β_{12}		0.001		-0.0005
	β_{22}		0.813***		0.957***

[2] Matrix coefficients are parameterized as diagonal such that all off diagonal elements are restricted to be zero.

	β_{32}		0.042**		0.049
	β_{42}		0.051		0.067
Variance Equation	γ_1	0.101**	0.844***	0.136	0.080***
	γ_2	0.204***	0.823***	0.022	0.925***
covariance equation	δ_1	-0.143***		-0.104***	
	δ_2	0.833***		0.144	
logL		-1085.41		-684.36	

In the mean equation for Korean stock price, interest rate (β_{31}) is positive and statistically significant, whereas GDP (β_{41}) is negative but not significant. Hence, effect of the macroeconomic common factors on stock market mainly is captured through interest rate, possibly reflecting correlation between high interest rate and booming economic activities. Lagged home price (β_{21}) is negative, possibly reflecting the investor sentiment hypothesis, but is not statically significant. Both independent variables – the short memory shock (χ_1) and the long memory shock (χ_1) are highly significant, indicating heteroschedastic error variance.

In the home price equation, stock price (β_{12}) is positive but not significant, and interest rate (β_{32}) is positive and slightly significant. GDP (β_{42}) is positive and highly significant, indicating that key macroeconomic factor in the case of the Korean housing market is shown to be the GDP trend. Both variables in the variance equation are also highly significant, indicating time-varying volatility in the Korean home price process.

In the U.S. side, the stock price equation (mean) is shown to be influenced by interest rate (β_{31}), which is negative and significant, and GDP (β_{41}), which is positive and significant. Coefficient of the housing variable (β_{21}) is positive but not significant, showing an opposite result to that of the Korean case. In the home price equation, no variable (except its own lag) is significant. GDP (β_{42}) is also not significant, showing that home price dynamics in the U.S. is less tied to macroeconomic variable than in Korea

The variance equation of the U.S. housing market, both independent variables are highly significant, while they are not in the stock price equation. As we are using monthly time-series data, rather than more high-frequency data such as daily returns, shock in prior period's stock price may not influence current period's volatility.

Time-varying volatility patterns of home price dynamics in Korea are plotted in Figure 2. The standard deviation of the estimation errors is peaked in the late 1980s and early 1990s, with a range between 1 and 1.5, and has reduced since then, hovering around 0.5 in the late 1990s and 2000s. The volatility is also shown to increase at time of turning point, implying rising uncertainty in predicting the price trend around then.

Dynamic correlations between stock vs. housing markets in Korea are shown in Figure 3. The correlation increased sharply at the time of Asian financial crisis, and has been stabilized between zero and 0.1 since then. Overall, the correlation patterns are also shown to be time-varying.

In comparison, the volatility trend in the U.S. housing market is currently experiencing the unprecedented hike after the subprime mortgage crisis (Figure 4), reaching to 40% standard deviation right now. However, the vol pattern was reasonably stable before then with long-term mean around 15%. That was much lower than that in Korea, which is over 50% even in the more stable period of mid-1990s to current.

Correlation pattern of the U.S. stock and housing markets are generally shown to be lower than that in Korea (Figure 5); It is being low and even negative in 2000s, except in the periods of market turning points where the correlation tends to go up as in Korea.

Figure 4. Time-varying volatility (S.D): Housing market in Korea :

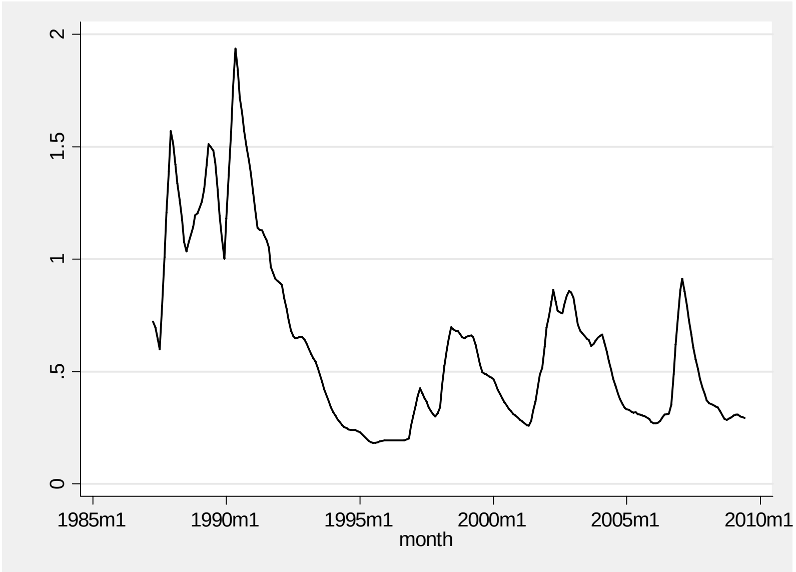


Figure 5. Correlation dynamics: Stock-Housing markets in Korea

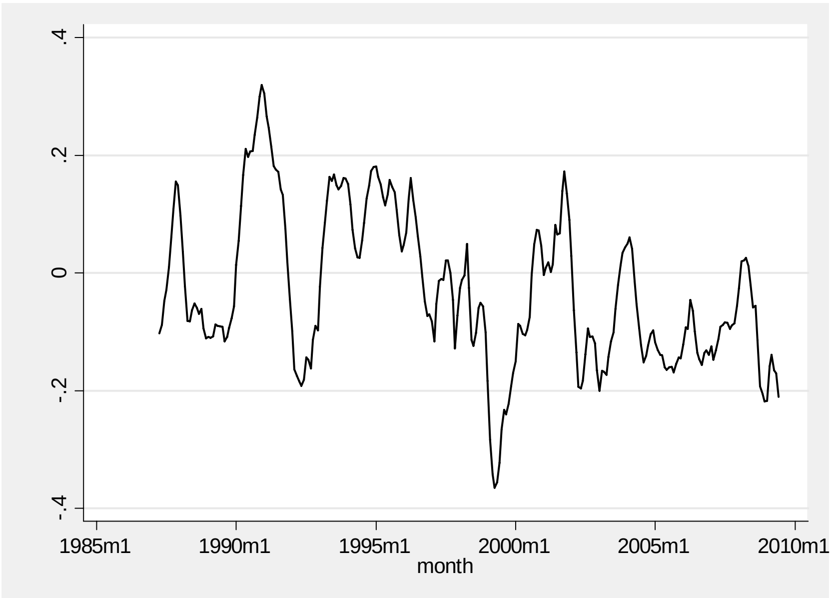


Figure 6. Time-varying volatility (S.D): Housing market in USA

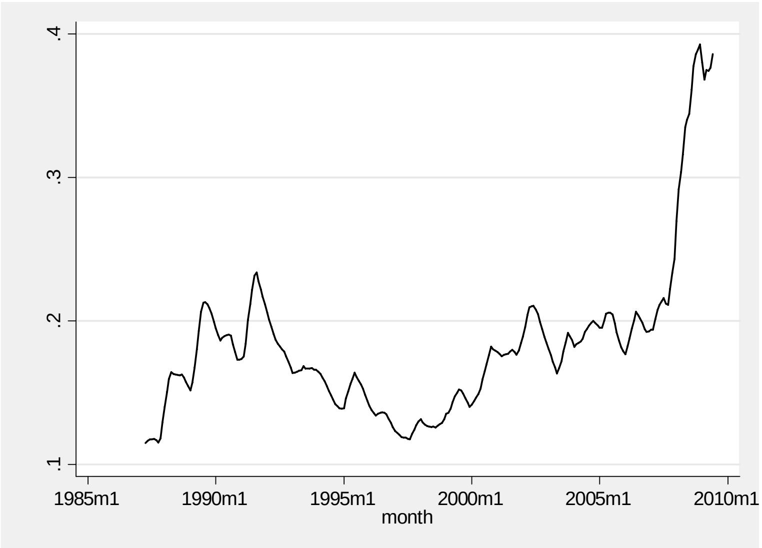
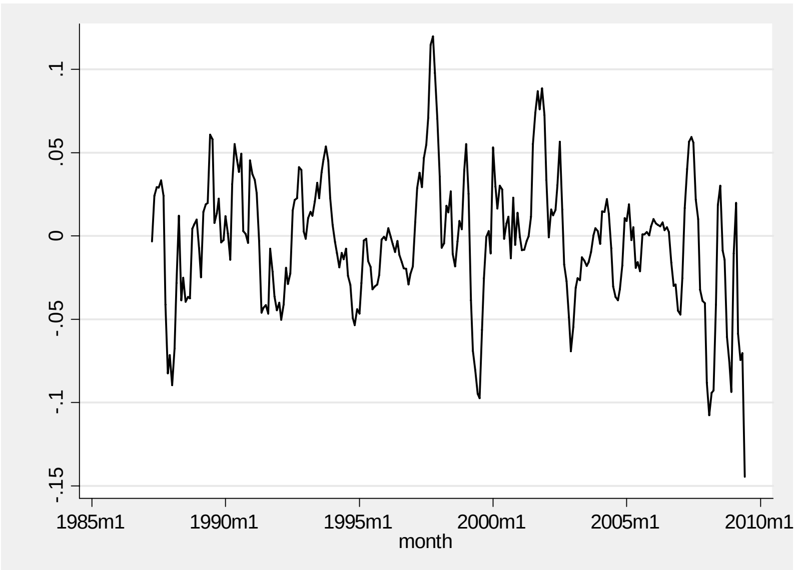


Figure 7. Correlation dynamics: Stock-Housing markets in USA



Univariate GARCH model: AR (1)-GARCH(1,1) Model Estimation

For comparison purpose, univariate GARCH models are estimated, with no consideration of inter-market linkage, and results are reported in Table 4. Unlike the multivariate model outcomes, both interest rate and GDP are significant in the home price equation of Korea, while no variable (other than its own lag) is significant in the stock price equation.

In the variance equations, both loan and short memory shocks are significant in the stock equation, whereas only short memory shock is significant in the home price side. In the U.S., independent variables in the stock price variance equation, both of them, are not significant, while they are highly significant in the home price variance equation.

Alternative Model, Model 2: Univariate GARCH model

- Time-varying volatility, without contemporaneous market linkage (i.e without time-varying correlation)
- Some differences from our main model, the time-varying correlation model, being observed: the stock price model for Korea is virtually same; for housing return for Korea, both GDP and interest rates are significant in the mean equation, the LT vol in the volatility equation (gamma 2) is now not significant
- For the U.S., the results are roughly same between Tables 3 & 4

Table 4. Univariate AR(1)-GARCH(1,1) Model: KOREA & USA

Univaraite GARCH		Korea		USA	
		Stock	housing	stock	housing
Mean equation	β_{11}	0.318***		0.078	
	β_{21}	-0.161		0.374	
	β_{31}	0.398		-2.290**	
	β_{41}	-0.319		2.036	
	β_{12}		-0.0019		-0.0006
	β_{22}		0.630***		0.957***
	β_{32}		-0.074***		0.053
	β_{42}		0.043**		0.068
Variance Equation	γ_1	0.102**	2.183***	0.177*	0.076***
	γ_2	0.844***	0.017	-0.147	0.936***

logL	-876.53	-191.38	-771.50	85.96

Alternative Model, Model (1) : non-time varying VAR model

- Time-invariant volatility, with contemporaneous market linkage, and time-invariant market correlation
- Differences from Table 3: In the stock return equation in Korea, the interest rate is now significant; For housing returns in Korea, GDP is now significant; For the stock return in the U.S., both exogenous variables are now significant; For the U.S. housing market, none of the exogenous and endogenous variables is significant

Table 5. Non-time varying volatility model: KOREA & USA

VAR model		Korea		USA	
		Stock	housing	stock	housing
Mean equation	β_{11}	0.382***		0.099*	
	β_{21}	-0.154		0.210	
	β_{31}	1.230***		-2.094**	
	β_{41}	-0.223		2.591***	
	β_{12}		0.008		0.001
	β_{22}		0.697***		0.953***
	β_{32}		0.013		0.070
	β_{42}		0.101***		0.079
logL		-1157.48		-714.6	

Estimation of city-level home price equations

Time-varying correlation model

	Gangnam		Gangbuk		Busan	
	Stock	housing	Stock	housing	Stock	housing

Mean equation	β_{11}	0.349***		0.336***		0.314***	
	β_{21}	-0.070		-0.076		0.281	
	β_{31}	0.343		0.224		-0.076	
	β_{41}	-0.340		-0.464		-0.292	
	β_{12}		0.008		0.002		0.004
	β_{22}		0.639***		0.692***		0.726***
	β_{32}		0.050		0.065***		0.082***
	β_{42}		0.055		0.060***		0.045***
Variance equation	γ_1	0.062**	0.518***	0.063***	0.833***	0.090**	0.132***
	γ_2	0.891***	0.587***	0.875***	0.521***	0.874***	0.875***
covariance equation	δ_1	-0.180***		-0.230***		-0.109***	
	δ_2	0.723***		0.675***		0.875***	
logL		-1233.55		-1097.46		-1055.72	

The Gangnam's home price equation is shown to be less correlated with macroeconomic variables (GDP and interest rate), compared to other locations (Gangbuk and Busan); And in the local level, the stock market and housing markets are not shown to be correlated in the mean equation.

Judging from the variance equations, all three home price processes show time-varying volatility patterns. The stock market variance equations also have significant χ_1 and χ_2, but negative sign for the former. After mid-1990s, home price volatility in Gangnam surpasses those of other cities, with Busan showing the lowest level of volatility (Figure 6). The correlation patterns tend to be lowered in recent years as well (Figure 7).

Figure 8. Combined time-varying volatility patters

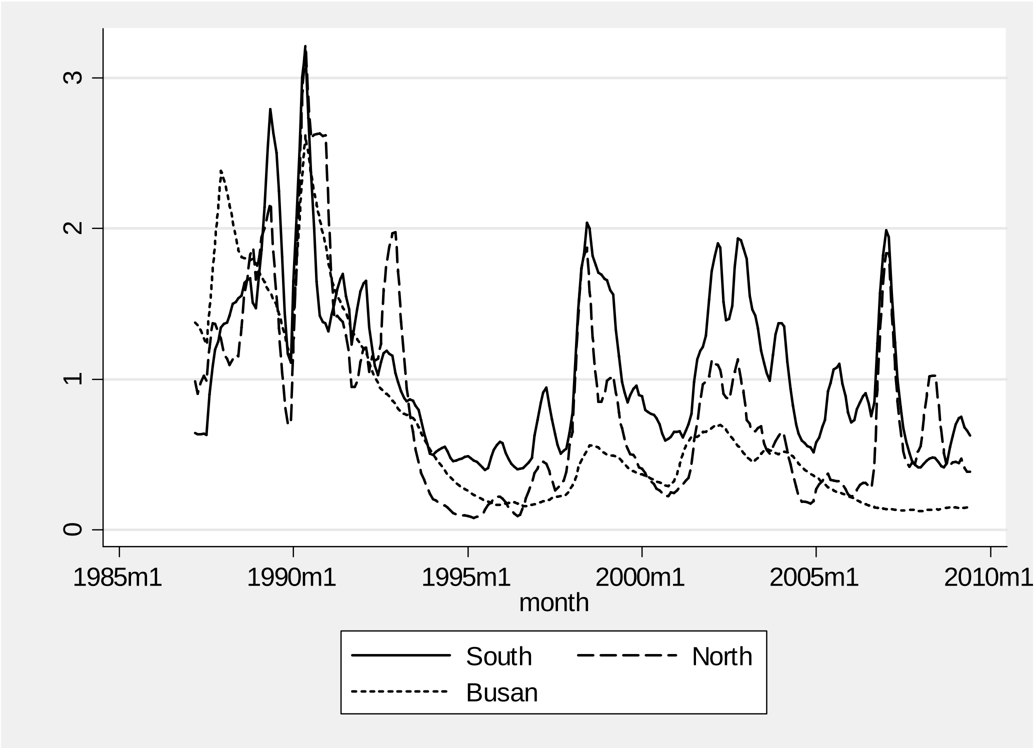
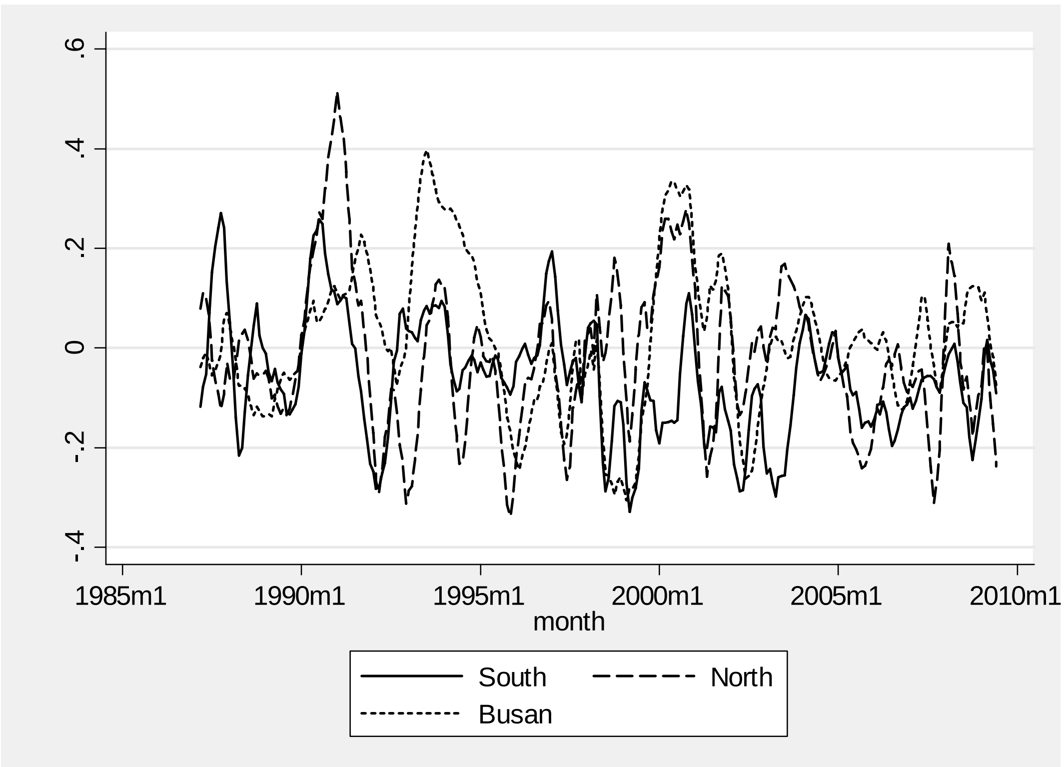


Figure 9. Correlation dynamics: Stock and city-level housing markets in Korea



V. VaR and Stress Testing

Single Asset VaR analysis

We performed stress testing based statistically-determined stress scenarios, i.e., VaR type analyses of right-tail stress event. Specifically, under the normality assumption,

$$\mathrm{VaR_t} = \mu_t + z_\alpha \sigma_t$$

where μ_t and σ_t are conditional mean and conditional standard deviation estimates by GARCH models. We then perform the following hypothesis test by assuming $\alpha = 0.05$ and $\alpha = 0.01$:

Hypothesis test

$$H_0: f = \alpha$$
$$H_1: f \neq \alpha$$

where f is defined as x/T and x is the number times in which observed returns exceed the estimated VaR. Testing statistics is the Kupiec (1995)'s LR test statistic. Under the null hypothesis, the test statistics is known to follow a chi-square distribution with one degree of freedom.

$$LR = -2\ln[(1-\alpha)^{T-x}\alpha^x] + 2\ln[(1-f)^{T-x}f^x] \sim \chi^2(1)$$

Based on historical data, we select 95% right-tail stress event, i.e., 5th most severe stress outcome in the home price trend. To that threshold, we count number of exceeding of predicted price changes based on the multi-variate GARCH models from the threshold set. The hypothesis test is done by performing significance test between the estimated VaR and the historical VaR ($\alpha = 0.05$ and $\alpha = 0.01$).

Table 6. The number of exceeding and LR test

	Stock	housing	housing-stock portfolio
$\alpha = 5\%$	16	8	15
p-value	0.469	0.105	0.649
$\alpha = 1\%$	3	2	3
p-value	0.842	0.666	0.842

Notes) 1.VaR is estimated by the multivariate GARCH model.

2. housing-stock portfolio: stock (20%) and housing (80%)

Under the multivariate GARCH model, the number of exceeding measured by VaR estimates is 8 in the housing market. Assuming $\alpha = 0.05$, the observed exceeding observation is 13.3 and this difference is statistically insignificant according to Kupiec's LR test. Under more extreme scenario $\alpha = 0.01$, the null hypotheis is not rejected at a 5% significance level. After generating portfolio return series, we calculate portfolio VaR estimates and apply the LR test as a verification test. Still the null hypothesis that the exceeding number by estimated VaR is statistically same as the historical exceeding number is not rejected. The test results imply that the multivariate model is appropriate in the risk assessment.

The 95th percentile stress home price scenarios are shown in figures below. In Korea, the most severe VaR outcome was during the Asian financial crisis, when the fitted stress home price change was negative 24% per annum. In the U.S. case, the post-crisis home price decline in recent years represent the most severe VaR home price change, recording also about negative 24%. The stress home price scenarios are shown to be time-varying as well.

Figure 10. Time varying VaR of housing market returns: Korea vs. U.S.

housing –only portfolio

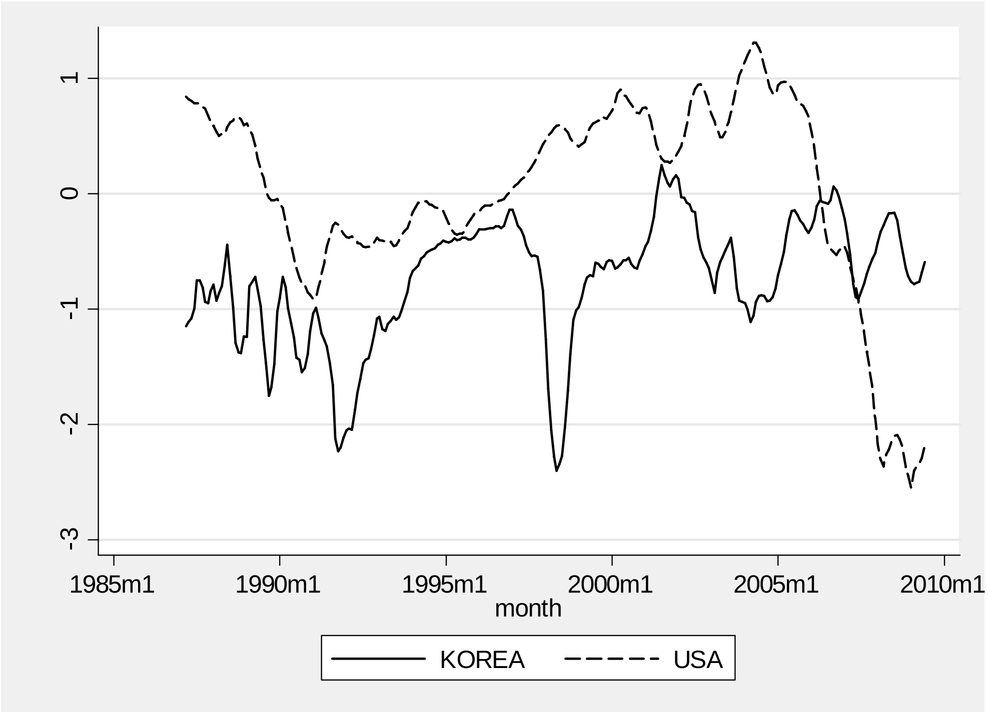


Figure 11. Time varying VaR of housing market returns : Korean cities

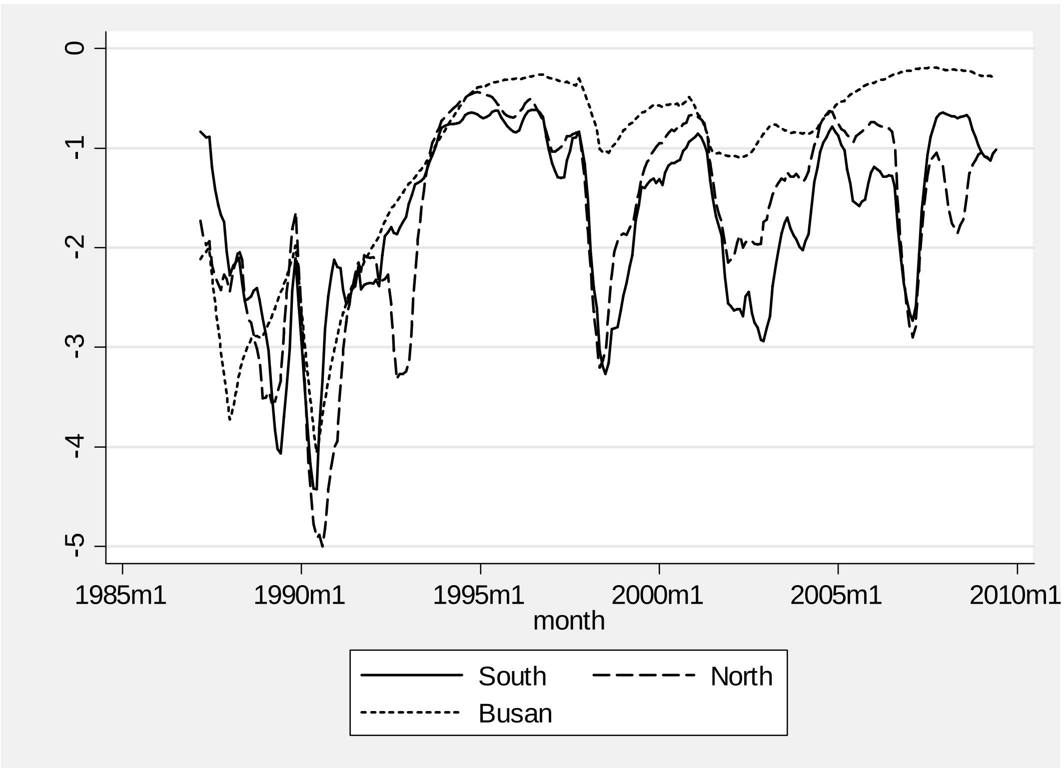
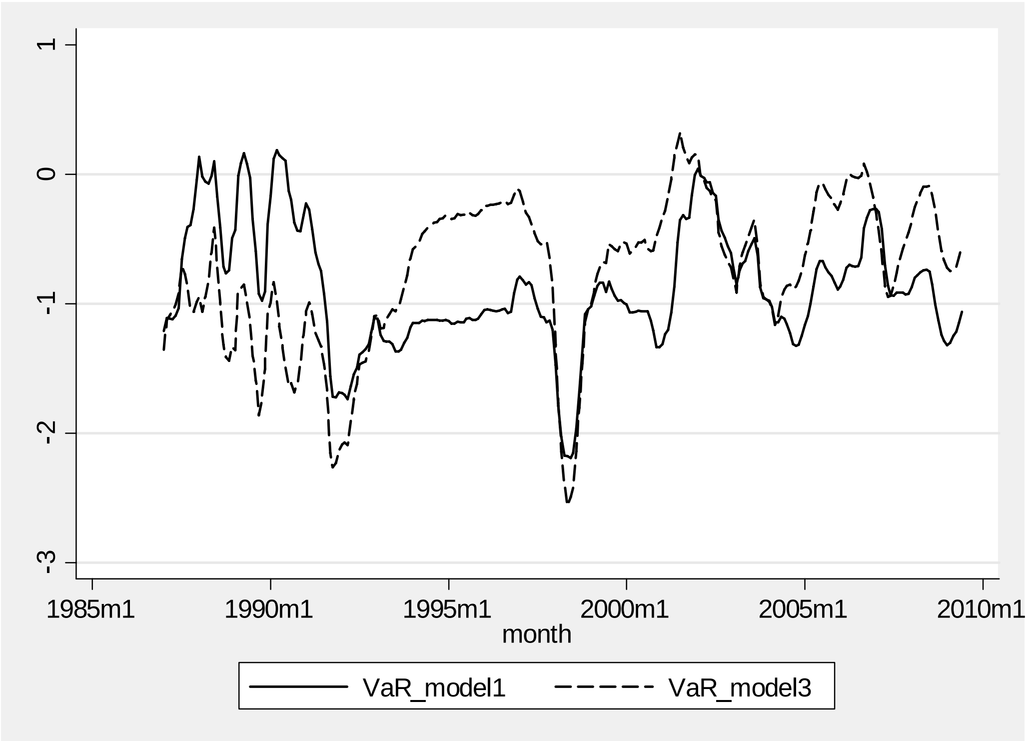


Figure 12. Model1 & Model3

Housing-only portfolio VaR



Portfolio VaR Analysis

Next, we assume a portfolio of 20% stock and 80% housing in Korea, and perform the same VaR analysis for portfolio-level risk-return. Specifically, the portfolio VaR is defined as,

$$\mathrm{PVaR}_t = \left(0.2\mu_t^{\mathrm{stock}} + 0.8\mu_t^{\mathrm{housing}}\right) + z_\alpha \mathrm{sqrt}[0.2 * 0.2 * \sigma_{\mathrm{stock},t}^2 + 0.8 * 0.8 * \sigma_{\mathrm{housing},t}^2$$

$$+ 2 * 0.2 * 0.8\sigma_{\mathrm{stock,housing},t}]$$

Results are shown in the figures below. In general, PVaR outcomes are more severe than the market-level VaR analyses discussed earlier. For example, the most severe PVaR home price decline is almost minus 50%, about twice deeper down turn compared to the market level outcome.

Figure 13. Time-varying Portfolio VaR: Korea vs, U.S

Housing 80% and Stock 20%

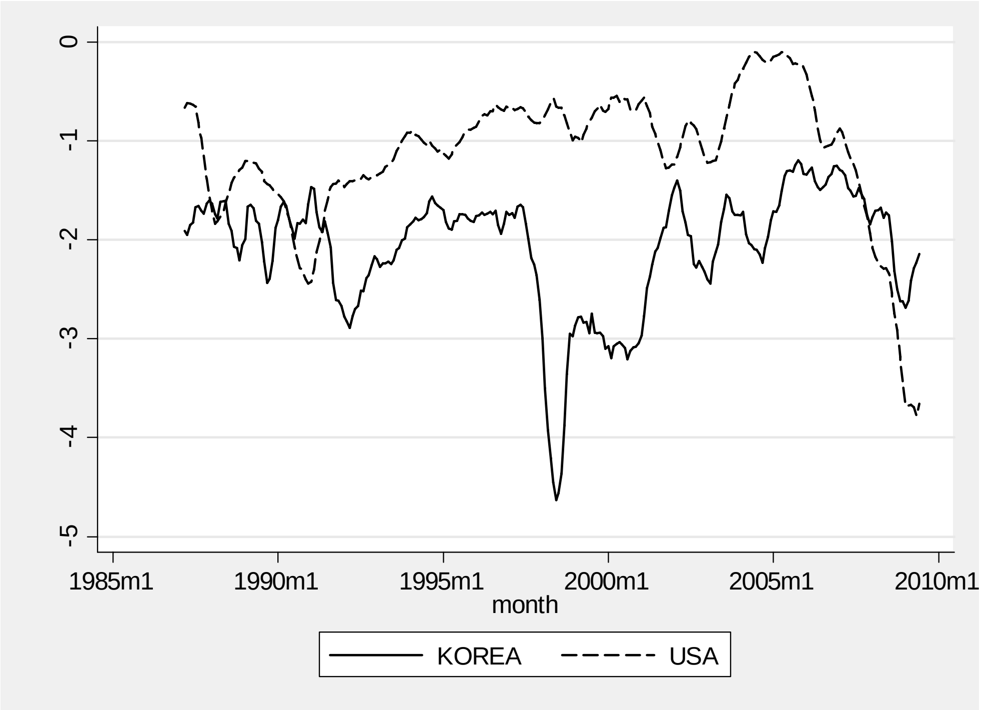
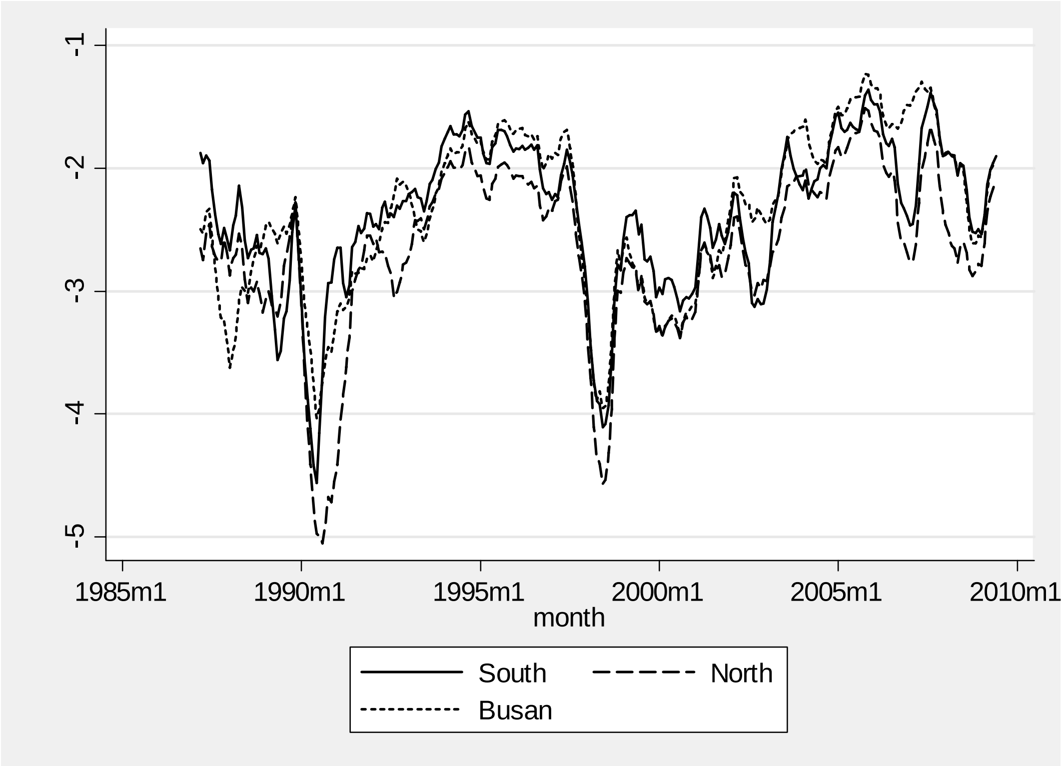


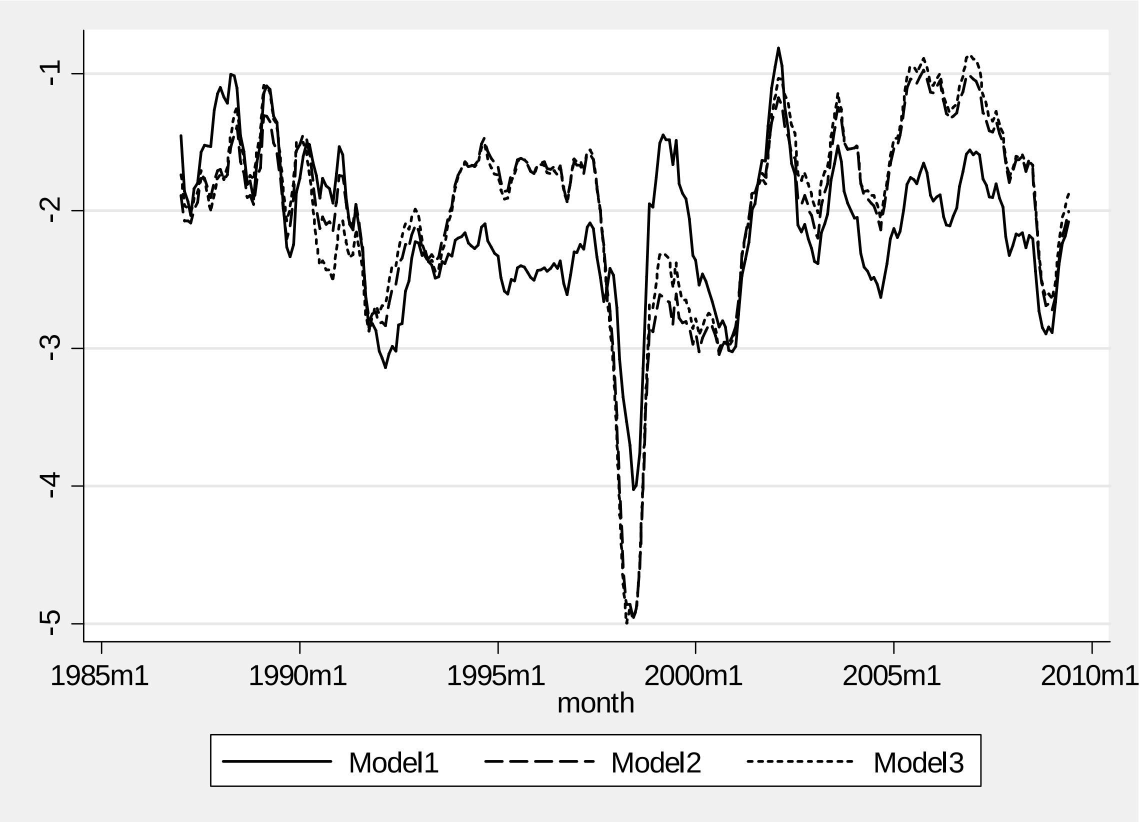
Figure 11. Portfolio VaR: Stock 20% and Housing 80%

Housing 80% and Stock 20%



KOREA : Model1, Model2, Model3

Housing 80% and Stock 20%



VI. **Policy Implications & Concluding Remarks**

This paper investigates price processes of two major assets in Korea and the U.S. – housing and stock, in terms of mean and volatility of each as well as correlation between the two. Our results show that, unlike the stock prices, volatility and correlation patterns of housing prices in both countries are highly time-varying and tend to increase during times of turning points in the price processes. The results imply that uncertainty rises in predicting price trends around turning points, and that the correlation between asset markets increases sharply at the time of stress event, such as the Asian financial crisis in the case of Korea and the subprime mortgage crisis in the case of the U.S.. In terms of the stress testing, our results show that the univariate GARCH model under-predicts home price risk, implying that considering correlation between asset markets is important in such analyses.

In subsequent analysis, we will further elaborate out finings in terms of performing stress test to gauge financial institutions' safety and soundness, as well as macro-prudence regulations. Specifically, implications of our analyses to forming forward-looking housing price distribution and its application to gauging systematic risk in asset portfolio will be further examined. There are also a series of related future research issues that we plan to investigate going forward, such as extension of the VaR analysis with firm-level financial data, inclusion of another asset class into the model (e.g., currency exchange market), and conditional VaR analysis (or CoVaR). As discussed in Section II, comparing different asset price models, e.g., VAR, ECM, ARIMA, and even a random walk model, can be another area of future research as well.

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